FLIGHT ACOUSTICS MEASUREMENT TECHNIQUES AND APPLICATIONS

J. S. Preisser and M. A. Marcolini

NASA Langley Research Center
Hampton, Virginia 23681-2199, U.S.A.

1. INTRODUCTION

Careful consideration must be given to data acquisition and analysis techniques in the design of experiments for the measurement of noise generated by flight vehicles. Although noise measurement locations and data reduction procedures are specified for aircraft certification by FAA and ICAO directives, for example, there are virtually no established procedures for aircraft noise measurement for other purposes. To optimize the quality and quantity of information obtained in a flight acoustics experiment, microphone layout, data acquisition, and analysis must be tailored to the specific test objective.

This paper will review flight acoustics technology at NASA Langley Research Center developed over the past decade. In particular, the paper will focus on flight experiments performed for three diverse objectives: (1) research applications, such as noise prediction code validation, (2) noise impact modeling, and (3) noise abatement flight procedures. To best achieve these diverse objectives, different deployments of microphone systems on the ground are required, and different data analysis techniques are needed. In all cases, accurate positioning of the aircraft synchronized in time with the data recording is necessary. However, there are some restrictions on flight operations unique to each case for the methods to properly work.

2. MEASUREMENT AND ANALYSIS

Research Applications

For flight acoustics research applications, such as noise prediction code validations studies or wind tunnel/flight data comparisons, it is often desired to have a high quality, well documented, and very accurate data set. A technique called ensemble-averaging can be implemented to greatly decrease the error band of the amplitude of flight noise spectra.

It can be argued that the acoustic source field produced by an aircraft moving at constant altitude, speed, attitude, and engine power setting through a uniform atmosphere represents a stationary random process. The acoustic signal received from a moving aircraft at a fixed observer position, i.e., microphone location, however, is clearly nonstationary. In addition to the well-known Doppler effect, the characteristics of the spectrum of the received signal change because of the directionality of the source, spherical spreading, atmospheric absorption, and ground reflection and attenuation. Since the techniques of time series analysis are valid only for data which satisfy conditions of weak stationarity [1], the received acoustic signal can only be assumed to be weakly stationary over some sufficiently small time interval. However, small analysis time intervals result in few statistical degrees of freedom and poor confidence in sound pressure level. To circumvent this dilemma, a technique of ensemble-averaging spectra over several microphones spread out in a linear array, may be used. Here, the test aircraft flies at constant speed, altitude, and power setting along the array.

The procedure for reducing the experimental data is depicted schematically in Figure 1 and is as follows: Directivity angle Θ is calculated from tracking the aircraft position. Microphone reception time t_r

is calculated by assuming the sound to propagate in a straight line at a constant average speed determined from meteorological data also obtained during testing. The average velocity of the aircraft during the flyover is also calculated to account for small variances in the nominally constant speed. To analyze the data according to directivity angle, data records are interpolated to determine signal reception times corresponding to the emission angles of interest.

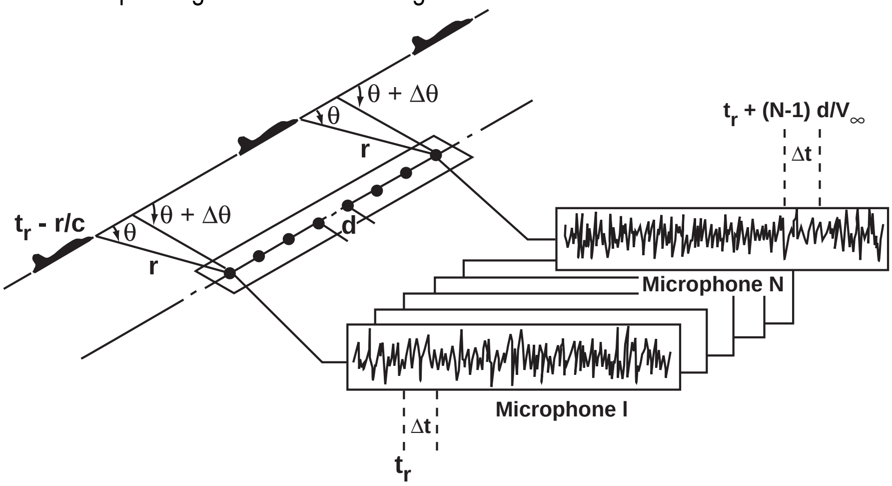

Figure 1. Schematic depicting ensemble-averaging technique.

In order to ensemble-average spectra from different microphones, the individual spectra must be calculated using data segments corresponding to identical aircraft-to-microphone directivity angles. Since the microphones are equally spaced along a line parallel to the flight path, it is necessary to shift the data for each microphone by a time equal to $(N - 1)d/V_\infty$, where d was the distance between successive microphones, V_∞ the average velocity of the aircraft, and N the number of the microphone.

For each time corresponding to a directivity angle of interest, one segment of data centered on that time is found for each microphone. After applying an appropriate data window, a block-averaged spectral estimate is made for each segment. The block-averaged spectra corresponding to each directivity angle of interest are then averaged over all microphones.

This technique has been applied to several different flight experiments, including a high speed flight effects test utilizing a turbojet-powered military training aircraft aimed at validating an existing NASA noise prediction code, and a wind tunnel-to-flight comparison test utilizing a small turbofan engine [2]. In the former, a 10-element array was deployed to produce 24 Hz-band width narrowband spectra with 80-percent confidence interval of about ±1.4 dB. In the latter, an 8-element array was used in a 100 Hz bandwidth analysis for a ±1.0 dB amplitude resolution.

Noise Impact Modeling

A Rotorcraft Noise Model (RNM) [3] is currently under development at NASA, which calculates sound levels at receiver positions either on a uniform grid or at specified defined locations. The basic computational model calculates a variety of metrics and is most useful for noise impact modeling studies. Acoustic properties of the rotorcraft noise sources are defined by two sets of sound hemispheres, each hemisphere being centered on a particular noise source. One set of sound hemisphere data provides broadband data in the form of one-third octave band sound levels; the other set provides narrowband data in the form of pure tone sound pressure levels and phase. Typically, hemispheres from each set are paired together to model all the noise emanating from one noise source for a particular operating condition. For a given rotorcraft, a number of sound hemisphere pairs can be input to RNM describing different vehicle operating conditions, such as aircraft speed and flight path angle. Sound hemispheres, in principle, could be obtained from noise prediction codes but the state-of-the-art is such that accurate prediction of all noise sources of any given rotorcraft is still in the future. To fill the current need, a technique for efficiently estimating rotorcraft source noise was developed using measured sound fields [4]. This technique is now described.

As was the case for ensemble-averaging, a linear array of microphones is used. But as shown in Figure 2, the array is deployed perpendicular to the flight path. For purposes of graphic simplicity, Figure 2 depicts a 4 step procedure for an aircraft in level flight. In step 1, acoustic data are continuously recorded as the vehicle flies over the microphone array. The acoustic directivity in three dimensions (r, Θ, Φ) can be effectively sampled at the array, if the microphone recording times are synchronized with the tracking time of the vehicle position. Step 2 depicts the translation of data from a signal reception time at the microphones to a signal emission time at the source, based on knowledge of the propation path and the speed of sound. In step 3, coordinate transformations are used to move from a ground-based emission time reference to a vehicle-fixed location point. This results in the generation of an acoustic surface contour. In the final step 4, effects of ground impedance, atmospheric absorption, and spherical spreading are applied as corrections to the measured data. The result of these calculations is a free-field, lossless acoustic source sound field at a constant radial distance (e.g., a few rotor diameters). Data acquired and processed in such a manner for a variety of flight conditions can be input to RNM, which in turn, can re-propagate these source descriptions for a broad range of segmented and non-segmented flight paths producing fairly accurate ground contours. Noise contours on the ground derived in this manner are suitable for inclusion in Environmental Impact Statements or Environmental Assessments. This method has been successfully demonstrated for helicopters [5] and tiltrotor aircraft [6].

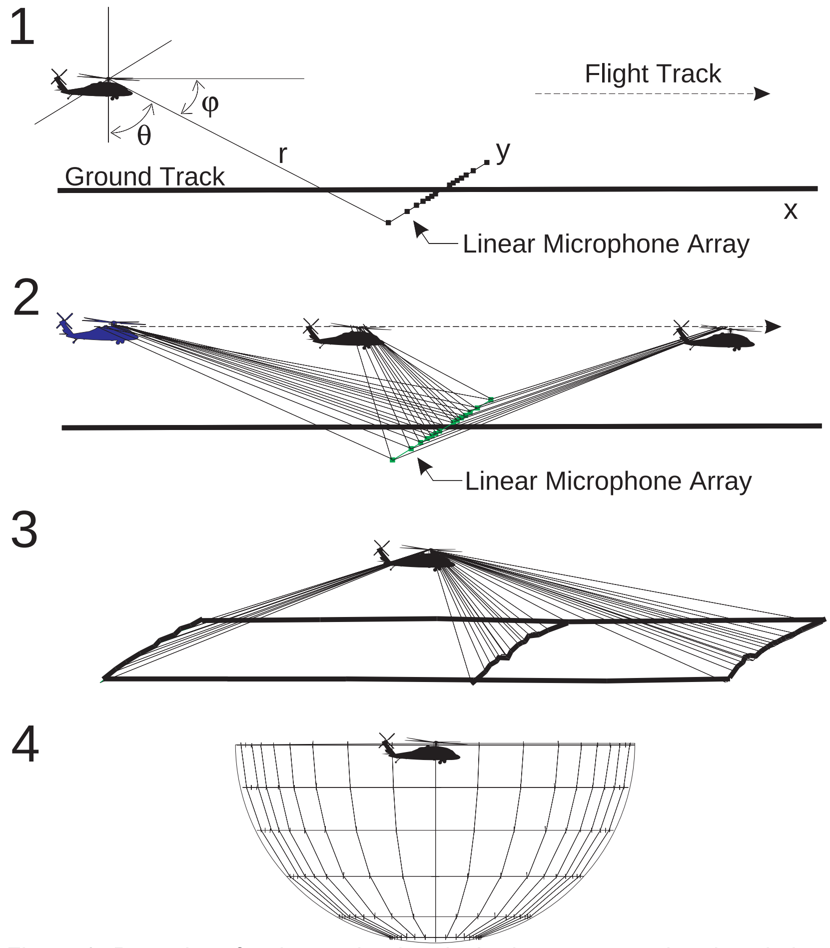

Figure 2. Procedure for developing hemispherical source noise description.

Noise Abatement Flight Procedures

Noise abatement refers to the modification of flight procedures to achieve quieter aircraft takeoffs and approaches for reduced community noise impact. Changes in procedures may be changes in aircraft speed, glide slope, acceleration/deceleration rates, banks/turns, etc. Procedures of these types render use of either linear array previously described meaningless, since the quasi-steady requirement for flight condition is violated. Moreover, noise abatement data is needed over a very large ground area to measure community impact and for land use planning. Therefore, use of a ground planar array containing many microphones should be utilized. One such array, useful for helicopter noise abatement studies during approach, is depicted in Figure 3. This array covers an area of approximately one half square mile (8000 ft. long by 3000 ft. maximum width) and consists of 49 microphones. Tradeoffs to be considered in microphone placement are reducing the width of the array to obtain better resolution in noise footprints versus expanding the width of the array to capture a larger area for evaluation. The number of microphones uprange of the hover pad are maximized to support noise abatement procedures originating some distance from the pad. The shape of the array is designed to capture the roughly teardrop shape of the anticipated noise contours for a rotorcraft performing approaches to the hover pad. The array is widest near the hover pad where the noise levels are anticipated to be the greatest, and the width is reduced with increasing distance from the hover pad.

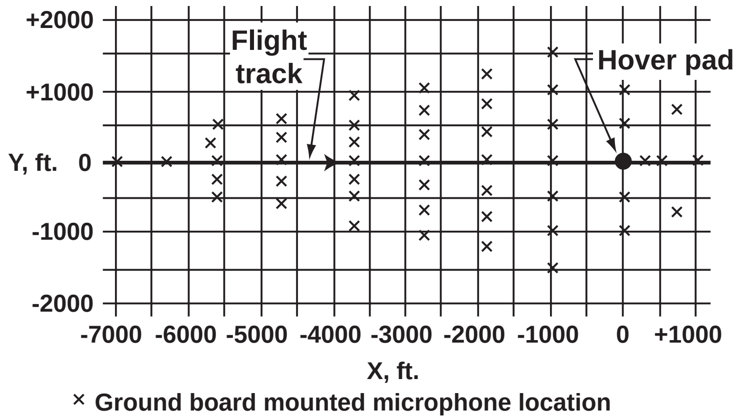

Figure 3. Large area microphone layout for use in noise abatement flight research.

Useful noise metrics for community noise impact are A-weighted Sound Pressure Level (LA) and Sound Exposure Level (SEL). LA contours calculated from the ground array data can be considered “snapshots” in time and are useful in assessing the noise generated during a particular segment of the flight approach. Integration of LA yields SEL contours, which are suitable for assessing the overall impact in the community and for land use planning exercises.

Noise abatement flight applications for both tiltrotor aircraft and conventional helicopters are described in references 6 and 7, respectively.

SUMMARY

Flight acoustic measurement and data analysis techniques must be tailored toward the specific test objective to gain maximum benefit from the non-trivial investment of resources necessary to do field tests. Where very high accuracy (~±1 dB) is required, such as for code validation or wind tunnel/flight comparisons, use of a linear array parallel to the flight path and ensemble-averaging of recorded data is the method of choice. If the objective is to obtain a full source description of the flight vehicle defined on a set of noise hemispheres beneath the vehicle for subsequent use in noise impact model studies, then flying perpendicular to a linear array can effectively provide the result. However, for noise abatement flight procedure testing where the aircraft state is varying in time, a large investment in many microphone systems, to cover a large ground area to produce the desired ground noise contours, is necessary.

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